Available online at www.sciencedirect.com
SCIENCE DIRECT®

Advances in Water Resources 27 (2004) 785–801

Advances in Water Resources

www.elsevier.com/locate/advwatres

Requirements of a global near-surface soil moisture satellite mission: accuracy, repeat time, and spatial resolution

Jeffrey P. Walker [a,b,*], Paul R. Houser [a]

[a] *Hydrological Sciences Branch, Laboratory for Hydrospheric Processes, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA*
[b] *Department of Civil and Environmental Engineering, The University of Melbourne, Parkville, Vic. 3010, Australia*

Received 11 September 2003; received in revised form 29 March 2004; accepted 4 May 2004
Available online 8 July 2004

Abstract

Soil moisture satellite mission accuracy, repeat time and spatial resolution requirements are addressed through a numerical twin data assimilation study. Simulated soil moisture profile retrievals were made by assimilating near-surface soil moisture observations with various accuracy (0, 1, 2, 3, 4, 5 and 10%v/v standard deviation) repeat time (1, 2, 3, 5, 10, 15, 20 and 30 days), and spatial resolution (0.5, 6, 12 18, 30, 60 and 120 arc-min). This study found that near-surface soil moisture observation error must be less than the model forecast error required for a specific application when used as data assimilation input, else slight model forecast degradation may result. It also found that near-surface soil moisture observations must have an accuracy better than 5%v/v to positively impact soil moisture forecasts, and that daily near-surface soil moisture observations achieved the best soil moisture and evapotranspiration forecasts for the repeat times assessed, with 1–5 day repeat times having the greatest impact. Near-surface soil moisture observations with a spatial resolution finer than the land surface model resolution (~30 arc-min) produced the best results, with spatial resolutions coarser than the model resolution yielding only a slight degradation. Observations at half the land surface model spatial resolution were found to be appropriate for our application. Moreover, it was found that satisfying the spatial resolution and accuracy requirements was much more important than repeat time.
Published by Elsevier Ltd.

Keywords: Soil moisture; Remote sensing; Mission requirements; Data assimilation; Modelling

1. Introduction

Data on land surface moisture is vital to understanding the earth system water, energy, and carbon cycles. Fluxes of these quantities over land are strongly influenced by a surface resistance that is largely soil moisture dependent. Soil moisture knowledge is critical in weather and climate prediction, where model initialization with hydrospheric state measurements has been shown to bring significant improvements in forecast accuracy and reliability [2,13,14]. Soil moisture observations will also benefit climate-sensitive socioeconomic activities, such as water management, agriculture, flood and drought monitoring, and policy planning, by extending the capability to predict regional water availability and seasonal climate. However, accurate land surface soil moisture observations are lacking, due to an inability to economically monitor spatial variation in soil moisture from traditional point measurement techniques. As a result, land surface models have been relied upon to provide an estimate of the spatial and temporal variation in land surface soil moisture. However, due to uncertainties in atmospheric forcing, land surface model parameters and land surface model physics, there is often a wide range of variation between different land surface model forecasts of soil moisture [16].

Over the past two-decades there have been numerous ground-based, air-borne and space-borne near-surface soil moisture (top 1–5 cm) remote sensing studies, using both thermal infrared and microwave (passive and active) electromagnetic radiation. Of these, passive microwave soil moisture measurement has been the most promising technique, due to its all weather capability, its direct relationship with soil moisture through

* Corresponding author. Address: Department of Civil and Environmental Engineering, The University of Melbourne, Parkville, Vic. 3010, Australia. Tel.: +61-3-8344-5590; fax: +61-3-8344-6215.
E-mail address: j.walker@unimelb.edu.au (J.P. Walker).

0309-1708/$ - see front matter Published by Elsevier Ltd.
doi:10.1016/j.advwatres.2004.05.006

the soil dielectric constant, and a reduced sensitivity to land surface roughness and vegetation cover [11]. However, to date there has been no dedicated space mission for the measurement of near-surface soil moisture. This is mainly due to the large antenna size (10's of meters) required for obtaining radiometric L-band observations at the desired spatial resolution (10's of km). As a result, scientists have resorted to making the best use of soil moisture information from non-optimal (i.e. C-band) sensors (e.g. [25]) and models [e.g. [20]).

Although current remote sensing technology can only provide a soil moisture measurement of the thin near-surface layer rather than the entire profile, there is a sizeable body of literature that has demonstrated an ability to retrieve the soil moisture content at much greater depths when this near-surface information is assimilated into a land surface model (e.g. [12,17,26–28,32–35]). Moreover, there is a great scientific demand for the soil moisture data that would be provided by such a mission [21].

While there is no current space-borne mission dedicated to soil moisture measurement, there are two missions in development stages. These are the European Space Agency passive L-band Soil Moisture and Ocean Salinity (SMOS) mission (2007 launch) and the U.S. National Aeronautics and Space Administration active/passive L-band HYDROSpheric states (HYDROS) mission (2009 launch).

Defensible global near-surface soil moisture measurement science and application requirements are vitally important for mission planning. In particular, mission planners need: (i) sensor polarization, wavelength and look angle requirements; and (ii) measurement accuracy, temporal resolution and spatial resolution requirements. (While satellite mission design must also consider the satellite overpass time, the main impact of this will be accuracy of the inferred near-surface soil moisture content, which will be a function of the specific remote sensing technique. Thus, we consider this as part of measurement accuracy.) The (i) requirements have been fairly well defined, with horizontally polarized <50° look angle [18,25] L-band [24] radiometer measurements, and horizontally polarized send and receive [31] C-band [8] 15° look angle radar measurements [30] yielding the greatest soil moisture sensitivities. However, the (ii) requirements have been less well defined. Apart from some "best guess" estimates by Engman [10] for spatial resolution (1–100 km), repeat time (1–10 days), measurement depth (top 5–10 cm) and accuracy levels (4–10%v/v) according to application, there are only the studies of Milly [22] and Hoeben and Troch [15], which recommend a daily repeat time, and Calvet and Noilhan [6], which recommends a 3 day repeat time. Finally, Jackson et al. [19] recommend without justification an accuracy of 4%v/v with a 10 km spatial resolution and 2–3 day repeat time.

Whilst L-band measurements are sensitive to a deeper layer of soil moisture near the earth's surface ($\approx$1/10 to 1/4 of the wavelength, depending on soil moisture, wave polarization, look angle, etc) than say C-band, the requirement for passive L-band measurements is the reduced sensitivity due to soil moisture signal masking by vegetation, rather than sensing depth. Moreover, Walker et al. [33] have shown that in the context of data assimilation, the near-surface soil moisture observation depth is relatively unimportant, providing the actual measurement depth is known and this matches closely the model near-surface layer thickness.

This paper seeks to defensibly address the yet unresolved global near-surface soil moisture measurement accuracy, repeat time and spatial resolution requirements. Although the scientific community is calling for a 2–3 day repeat time and 10 km spatial resolution with better than 4%v/v accuracy in low vegetation areas [19], this may have little scientific basis. Rather than limit this paper's scope to a specific soil moisture remote sensing technique (such as the passive microwave brightness temperature), we consider the inferred space-borne near-surface soil moisture content measurement accuracy, repeat time and spatial resolution requirements, independent of the measurement technique.

It should be recognized that there may be complex interdependencies between the accuracy, repeat time, and spatial resolution soil moisture mission requirements, and that there may be other important criteria that are not examined here (i.e. observation depth, model structure,, model objective, spatial scale of the model, simulation error and its representation, etc.). Hence, this study examines the sensitivity of each observation requirement for a given objective, rather than finding the optimum requirement combination. In light of the near impossibility of completely defining the interdependency between all possible observation requirements and application objectives, this paper makes some important first steps towards quantifying some defensible targets. The authors hope that this paper will lead to a plethora of studies on this topic with different model structures, resolutions and objectives, using both synthetic and real data, so that firm recommendations on mission requirements can be made.

4. Conclusions

This study has shown that the near-surface soil moisture observation error must be less than the required soil moisture forecast error, or slight model forecast degradation may result when used as data assimilation input. Typically, near-surface soil moisture observations must have an accuracy better than 5%v/v, but preferably better than 3%v/v. This study has also shown that assumptions in the assimilation framework lead to degraded forecasts when biased forcing and observations are used.